An on-line centralized computer-coupled automated laboratory information system using touch-tone card dialer telephone and audio-response technology for test order entry and result retrieval*

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INTRODUCTION

An important element in the evolution of the American Health Care System is the emerging recognition that many patients currently being hospitalized can be treated adequately on an ambulatory basis, thus relieving the pressure for hospital beds, reducing cost and eliminating the patients' separation from the home and family. Ambulatory Care Facilities (ACF) are being developed for these purposes in many medical centers.

The diagnostic departments play an important role in such ventures and the clinical laboratory stands in the forefront of that effort. Successful laboratory participation in an efficient ACF depends on the ability to perform rapidly a wide spectrum of tests with maximum reliability, accuracy and precision and to transmit promptly the results of those tests to the ACF physician to permit him to prescribe appropriate treatment without undue delay. In order to achieve maximum public acceptance of the ACF concept, it is necessary that the ambulant patient not be required to wait an inordinate period of time for examination by the physician, procurement and testing of specimens, diagnosis and definitive treatment. The crowded, chaotic, Out-Patient Department of yesteryear is no longer necessary or acceptable.

The Youngstown Hospital Association (YHA) Laboratory Information System (LIS) has been evolving over the past 20 years in fortuitous anticipation of these developments and suggests appropriate solutions to many of the problems which are perceived in ambulatory medicine.

The YHA comprises three, geographically separate, hospital units; North (540 beds), South (450 beds), and Tod Babies and Children's (TBC) (75 beds). The North and South Units are five miles apart and TBC is about 1000 yards from the North Unit. North and South possess conventional Emergency Departments which require urgently performed laboratory tests. TBC and the South Units have large, structured ACF's treating over 100,000 patients per year. Upon completion of a current construction program at the South Unit including new nursing stations and an ACF, a marked increase in ambulatory care is anticipated. In order appropriately to respond to the swelling tide of in- and out-patient tests, the Department of Laboratories embarked a decade ago on a program to restructure its facilities and operating modes, and is now capable of mastering tomorrow's challenges.

LABORATORY INFORMATION SYSTEM (LIS)

The LIS consists of six major sub-systems as follows:

Centralization (Specimen collection and transport)
Examination (Test performance)
Documentation (Computerization)
Communication (DIVOTS and terminals)
Retention (Data storage and retrieval)
Administration (Staffing, cost control, records, etc.)

Centralization*

The Centralized Laboratory of the total hospital system is located in the North Unit and contains optimally sized staff and space, and sufficient equipment to perform most of the routine and special procedures required by all patients in all units of the YHA. Blood Bank donor processing and Serology testing are localized at the South Unit.

The South Unit acts as a satellite but possesses sufficient in-house staff at all times and facilities to perform all urgently required tests. In addition there are several phlebotomists responsible for the collection of specimens. These are transported by hospital personnel in a frequent automobile shuttle to the North Unit Laboratory Triage area when they are merged with specimens collected from

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North and TBC patients. The specimens are immediately logged into the Spec-Ident (see below), centrifuged and brought to the appropriate laboratory division for analysis.

Without completely describing all details of this subsystem, it is self-evident that centralization allowing large volume testing leads to considerable economy of scale in terms of enhancing personnel productivity, space and equipment utilization. Thus it justifies substantial investments in the large scale, automated, analytic and computerized equipment to be described.

Examination

Laboratory tests are conventionally classified as Hematology, Biochemistry, Microbiology, Urinalysis, Blood Bank, Pathology and are carried out by registered Medical Technologists on specimens of blood, spinal fluid, urine, feces, and other human material under the supervision of clinical scientists and pathologists.

Tests are performed in three major modes: Automated, semi-automated, and manual ("handraulic"). In Figure 1, SMA 4, 6, 12 are automated and the devices, pH meter, Fibrometer, Spectrophotometer, etc., are semi-automated. These electronic instruments are coupled on-line to the in-laboratory dedicated computer by appropriate interfaces (SMART, INTFC) and multiplexors.

The computer (LDM-Laboratory Data Manager), manufactured by T & T Technology, Inc. (Madison, Wisconsin), is built around the Data General Nova 1200 Mini-computer.

Automatic, machine readable specimen identification is achieved by ID (Spec-Ident), punched stub-card readers (below) which also communicate directly with the LDM. The test instruments emit a wide variety of digital, wave form or steady-state analogue, linear and non-linear signals and the data are reduced to final concentration either by hardware or software in the LDM.

Results of manual tests such as Urinalysis, Blood typing and Bacteriology, are entered into the LDM by laboratory
personnel through the use of Port-A-Punch cards or terminal keyboards, or CMC/ST.\textsuperscript{a}

The automated and semi-automated devices permit complete hands-off performance, eliminating manual transcription of collection, loading or work lists, result calculation and specimen identification, all functions carried out by the computer.

\textit{Documentation—Computerization}\textsuperscript{b,d,e}

The YHA centralized computer unit (CPU) consists of an IBM 370/135 System. Using CICS as a teleprocessing monitor, message switching is accomplished through terminals and the other computers. All patient demographic, medical and fiscal information is on file (PMF).

The IBM S/7 is a 20K mini-computer with a disk module, audio-response unit and possessing teleprocessing capability. One disk pack contains an 852 word audio-vocabulary of medical and laboratory administrative words. Figure 1 also demonstrates the configuration of the telephone network between the various units, the LDM, the 370 and the S/7 computers and their terminals.

The paperwork flow of a clinical laboratory may be divided conveniently into three major sectors. Front End, Middle and Rear End.

\textbf{Front End}

Front End Documentation includes the creation of the patient’s basic demographic data base within the CPU. This includes all of his salient personal data such as sex, age, address, clinical diagnosis, previous admission to the hospital, financial status, etc. These data are inputted on line into the CPU from Admitting or ACF through terminals at the time of admission. The PMF is identified with a unique hospital number possessing a self-check digit; a non-detachable wrist band is applied. This bears a printed label describing the patient’s identity and small pressure labels bearing the hospital number (infra).

\textbf{Order Entry Routine}

Physicians request tests from the laboratory by writing their orders in the patient’s medical record. The actual ordering process is accomplished by nursing ward personnel. At YHA we have created an audio-response system—DIVOTS (Direct Input Voice Output Telephone System) which permits the generation and transmission of those orders directly from ward or ACF to the laboratory by telephone-computer coupled technology.

DIVOTS requires the use of Touch-Tone (T.T.), card-dialer telephones located at the nursing stations (Figure 1). Currently there are three trunk lines from the hospital switchboard connected by WE403E modems to the System/7. It also possesses a commercial line bypassing the hospital switchboard to permit physicians to use DIVOTS from their office or home or to insure privacy.

YHA is in a rotary telephone region and thus it is necessary that a T.T. pad, card-dialer accessory be attached to all rotary phones on Nursing Stations, ACF and special treatment areas including CCU, ICU (Coronary Care and Intensive Care Units), Surgery, Dialysis and Emergency Departments (Figure 2).

Physicians’ offices have the option of using T.T. pads or a portable attachment which can convert a conventional phone to T.T. capability (Interface Technology, Inc.). This consists of a transmitter placed over the mouth piece and is attached to a battery-powered T.T. pad. Thus, any telephone anywhere can be utilized efficiently, economically and rapidly.

To order a test, the DIVOTS extension number is dialed on the rotary phone. System/7 responds with a vocal message to enter a specified request. A unique, previously prepared, patient’s dialer-card permits automatic entry of his hospital number into the system which also may be done manually without a card. Within three seconds, the audio-response system verifies the identity of the patient by spelling out the first six letters of his name. Other data including the patient’s ward and the time of the physician’s order, are entered followed by test identification numbers as listed in an available Directory.

As soon as the test code is entered, DIVOTS states its name, thus verifying the request and assuring absolute accuracy of the two most vital test reliability factors, the name of the patient and the name of the test. If incorrect numbers are entered, the word “Error” is heard. Special instructions may be added through appropriate code numbers. As soon as the transaction is completed, a printer located in the laboratory and connected to the IBM 370, may print that patient’s demographic, logistic and test information on appropriately designed, sequentially numbered and prepunched stub-card requisitions (Figure 3).
The patient’s hospital number is automatically collated with the preprinted and punched requisition bearing the specimen number. This is accomplished as follows:

The number of the first sequentially printed and punched, fan-folded requisition is initially entered into the 370 manually, through the LDM. The 370 automatically merges the inputted requisition number with the patient’s hospital number and thus achieves identification of each requisition according to the patient and his data base. This merge is continuously carried out and monitored automatically by the 370 on all subsequent patients’ orders and requisitions.

This process resembles the conventional method employed in industrial organizations where the employee’s number and pre-numbered check are collated. The 370 simultaneously creates a record of this transaction which is sent to the LDM and to the billing files within the 370 for further processing. Thus, the patient’s identity may be ascertained from the specimen number in the LDM. The clock times of the physician’s order and DIVOTS input are automatically noted and the elapsed time is calculated.

**Specimen collection and identification**

Laboratory personnel removes the pre-printed and pre-punched requisitions from the printer. The requisition comprises an audit copy and six perforated stub-cards, each bearing the specimen number and the computer generated patient demographic information. The technologist goes to the patient and obtains the blood specimen. The printed identification data included on the patient’s wrist-band are rechecked visually against the requisition. One of the pressure labels bearing the patient’s hospital number previously attached to the wrist band, is removed and attached to the stub card permitting comparison with the printed hospital number and thus verifying the patient’s identification.

Various types of blood specimens in different tubes are collected. Stubs are attached to those tubes by means of special rubber bands.

Upon return to the laboratory Triage area, the stub-card is inserted into the Spec-Ident which identifies and records the time of arrival. The specimen, with attached stub-card, is then centrifuged if plasma or serum is required or
remains as whole blood, i.e., for Hematology tests. The specimens are then distributed by Triage personnel to the testing divisions and the actual bench-side examination is carried out.

In the automated and semi-automated, on-line systems, both specimen number and test data are merged and filed within the LDM automatically. Where manual testing is performed, the results are written on cards by the technologists and these data are key-punched or the technologists enter results directly on Port-A-Punch cards. All cards are read into the LDM and transmitted to the 370.

**Middle documentation**

Middle documentation may be roughly defined as that computer process which performs A/D conversion, peak picking, peak holding and similar types of data reduction. Through appropriate programs in the LDM, the instrumental outputs are compared with values of primary, reference standards and other materials, and computation of the patient's final results is carried out. Numerous quality control data checks are performed simultaneously to establish the accuracy and precision of the results and to create permanent records for validation. These results are collated with the specimen numbers and these data are merged with the patient's hospital number in the PMF in the 370.

**Rear end documentation**

After the test data are entered into the PMF, they become available for transmittal to the physician.

Interim results are printed at 12:00 noon daily on a Ward Report which is sent to all stations within the institution. The billing system is updated, exceptions are noted, and quality control reports are generated for permanent file.

These printed reports are transmitted by messenger to the appropriate nursing stations.

**Communication**

Audio-response communication of results by DIVOTS can be achieved. As soon as the test is filed in the patient's PMF, DIVOTS may procure the results and transmit them auditorily to the inquiring physician as follows. DIVOTS is telephoned as described above, a different transaction code is employed and the patient's hospital numbers are entered. The physician's private identification number is keyed in to permit only him to obtain the confidential medical information. He enters the test code and DIVOTS spells the patient's name, states the name of the test, the day the test was performed and the test results including the degree of normality. Physicians in the ACF, their offices or homes or, by long distance lines from distant locations, may interrogate the PMF at any time if knowledge of the patient's and test numbers is available.

**Autocall**

An important extension of DIVOTS rear end communication ability is the Autocall System which is used for:

- Certain divisions of the hospital with a "high need-to-know" factor such as CCU, ICU, Surgical Recovery, Emergency Room.
- Certain requests such as Emergency, ("stat"), requests.
- Specified substances or procedures such as Glucose, Potassium, drugs, Prothrombin time, etc.

These have been identified in the 370.

As soon as test results in any of these categories are transmitted by the LDM to the 370, the Autocall subprogram is initiated. Since the patient's ward and its telephone number is known in the PMF, the 370 informs the System/7 to dial the telephone at that place. Upon answering the phone, the hearer hears a series of chimes from the audio-response disk, identifying it as a DIVOTS call. The hearer indicates recognition of DIVOTS by entering the ward code. DIVOTS then automatically transmits the patient's name, the test name and the result repeatedly until the hearer hangs up.

Autocall therefore represents a sophisticated yet economical method of achieving automatic, rapid, and reliable data transmission to physicians requiring that information in situations where those data are of the highest medical importance. "Don't call us—we'll call you."

Although DIVOTS represents a widespread audio-communication system, there is also a network of CRT's in various places within the laboratory for test process control, data base maintenance and test result entry. Terminals are also available in the South Unit for reading punch cards and printing patients' results on the Ward and Patient Summary Reports simultaneously with similar activities at the North Unit (Figure 4).

Free narrative test reports such as Pathology diagnoses and consultations as well as any other free, unstructured reports and discussions, are entered into the PMF by means of the Communicating Magnetic Card/Selectric Typewriter (CMC/ST—IBM). These inputs are usually generated as byproducts of the transcription of the usual conventional pathology, EKG and microbiology reports, and thus represent a low cost, extremely efficient method of entering edited input. The magnetic card data are transmitted to the 370 by Data Sets through a dedicated dial-up port, shared with other CMC's in the institution.*

A special printout of laboratory data for laboratory operations, permanent quality control records and statistical data, are generated by the LDM Printer.
Retention (data storage)

All current laboratory information is stored in the 370 on disk and is immediately retrievable by DIVOTS, CRT's or printers. Each patient's laboratory record is retained during his entire period of hospitalization plus 15 days after departure from the institution at which time the stored data is transferred to magnetic tapes for permanent files.

The PMF may be interrogated at anytime. There are no paper files.

Administration

All Sub-systems exert an important impact upon the administration of the laboratory and thus, on the quality and cost of patient care, by increasing economy of operation and optimizing the productivity of the staff. Other benefits are:

- Reduction of manual transcription of test requests by nursing personnel.
- Elimination of time and expense in transporting requests from ACF and nursing stations of the laboratory.
- Elimination of expensive forms.
- Elimination of need for patient and test data input by keypunching or other terminals.
- Reduction of elapsed time between initiation of request by physician and availability of laboratory results.
- Elimination of all manual filing of millions of individual paper reports by storage of these data on magnetic tape.
- Creation of charges or credits for services automatically accomplished when the test request is initiated and result filed.
- Generation of important statistical and other administrative data as to the volume and types of procedures carried out.
- Documentation immediately of quality control of test.
- Achievement of maximum reliability of test data, patient and specimen identification.
- Availability of systems for backup support in the event of technical instrument or computer failure.
- Improving and accelerating the physician decision making process by furnishing him error-free data by phone wherever he may be.
- Creating printed documentation of the reliability of all steps of the test path pursuant to ethical, professional and legal requirements of quality care,
and according to the Rules and Regulations promulgated by Federal and State Laws (Medicare, Medicaid, Interstate Improvement Act of 1967—CDC, HEW, Social Security) or institutions.

The advent of Professional Standards Review Organization (PSRO), the Inspection and Accreditation Program of the College of American Pathologists, and similarly organized programs dedicated to the improvement of laboratory performance imposes mandatory requirements to create and retain extensive records during the test performance. These are automatically accomplished by appropriate software. In our completely automated systems, these requirements do not represent a significant added manpower, financial or systems burden.

CONCLUSION

From the foregoing, it should be obvious that the LIS and the Sub-systems which have been developed at The Youngstown Hospital Association are extremely useful in maximizing the functions of an ACF. We have described the need for, and means of, achieving rapid, error-free, patient and sample identification, procurement and transportation to the centralized laboratory, rapid automatic performance of the test and prompt transmission of the test data to the attending physician in the ACF while his patient is still there and can benefit by appropriately guided treatment. Thus, we believe that the major professional impact of the Youngstown LIS is focused on the "physician decision-making process".

Upon early receipt of the laboratory, EKG and other diagnostic information, his diagnosis may be confirmed, strengthened, changed or expanded and his treatment may be fine-tuned. Additional tests, other diagnostic (X-ray, EKG) procedures may be requested. The type, amount and form of medication may be reviewed, modified or discontinued. Consultation by other physicians may be requested. Admission to the hospital may be evaluated. All of the subtle decisions which underly professional care are buttressed by prompt availability of laboratory data.

The fact that the turnaround time is so short implies that these decisions can lead to performance of any of these additional acts while the patient is still in the ACF. This reduces the number of visits and eliminates the need to return at later dates.

Further studies are being carried out to determine the cost effectiveness, the systematic advantages and the technical requirements of the present system with the view of expanding the current LIS into a broader Medical Information System (MIS) by including such Sub-systems as Pharmacy, Surgical Scheduling, Dietary and Patient Logistics.

Industrial Engineering and Systems Design studies of this project are currently being carried out by members of the Department of Industrial Engineering of The Youngstown State University who, as Consultants, also act as our severest critics.

REFERENCES

8. Rappoport, Arthur E., Robert E. Berquist and William Gennaro, "The Communicating Magnetic Card as a Word Processor to Enter Pathology Narrative Reports and Clinical Laboratory Results into a Patient’s Computer Record," Laboratory Medicine, in press.